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# Investigation of multistage air-steam-blown entrained-flow coal gasification

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**Abstract.** The aim of the work is using an experimental-computational method to study the process of air-steam-blown entrained-flow gasification of coal with multistage air supply. To achieve this aim, the experiment was conducted on a plant consisting of a swirler into which coal and air are supplied, and a reaction chamber into which steam and multistage air are supplied; the experiment was numerically simulated using a validated CFD model; and the process under study was analysed using the obtained experimental and calculated data. The conducted experimental and computational studies of air-steam-blown gasification allowed determining the effect of steam supply and multistage air supply on the features of the gasification process. Steam injection lowers the temperature of the gas mixture and increases the concentration of hydrogen due to the hydrogasification reaction. The air supply to the reaction chamber increases the temperature of the mixture due to the burning of part of the syngas, while the syngas heating value is reduced by an appropriate amount. The maximum concentration of the syngas combustible components (and hence syngas heating value) is observed before the second point of air supply to the reaction chamber.

## 1. Introduction

The gasification of solid fuel, in particular coal, is found in many energy units: gasifiers, steam boilers, activated carbon plants, etc. In gasifiers, coal is converted to synthesis gas (syngas), which is then used to generate heat and electricity [1] or to produce chemicals. In power boilers, gasification is the process preceding the combustion of coal. In the production of activated carbon, partial gasification takes place, resulting in the formation of a coal coke residue. To improve the gasification process, several methods are used, such as a multistage supply of reagents, steam injection, increasing temperature, pressure, etc.

The multistage supply of reagents (as well as steam injection) allows controlling the temperature and concentration of reagents in certain areas of power plants. It has long been widely used in the energy sector, for example, in power boilers to reduce the formation of thermal nitrogen oxides, multistage (three-stage, reburning) combustion is used [2]. In gasification technology, this principle helps to solve many problems [3]: to increase the chemical efficiency, the carbon conversion rate, to ensure stable slag removal [4], etc.

The aim of the work is an experimental-calculation method to study the process of air-steam-blown entrained-flow gasification of coal with multistage air supply.

To achieve this aim, the following tasks were solved:



- 1) experiment on a plant consisting of a swirler into which coal and air are supplied, and a reaction chamber into which steam and multistage air are supplied;
- 2) numerical simulation of the experiment case using a validated CFD model;
- 3) analysis of the process under study using the obtained experimental and calculated data.

## 2. Materials and methods

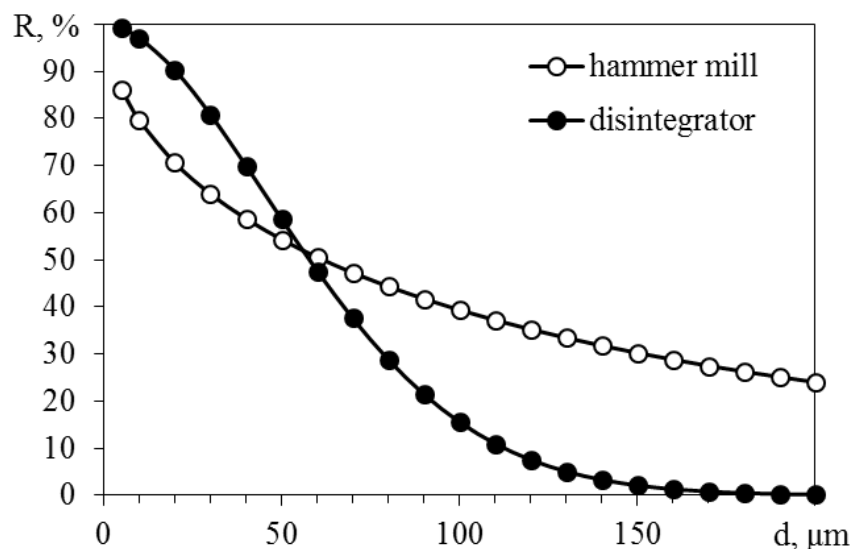
### 2.1. Materials

The experiments were carried out with oxidized bituminous Kuznetsk coal (grade D). The results of approximate and ultimate analysis of coal are shown in table 1.

**Table 1.** Approximate and ultimate analysis of coal.

W, %	A <sup>d</sup> , %	V <sup>daf</sup> , %	C <sup>daf</sup> , %	H <sup>daf</sup> , %	O <sup>daf</sup> , %	N <sup>daf</sup> , %	S <sup>daf</sup> , %
2	21	41	74.5	4.9	17.7	2.2	0.6

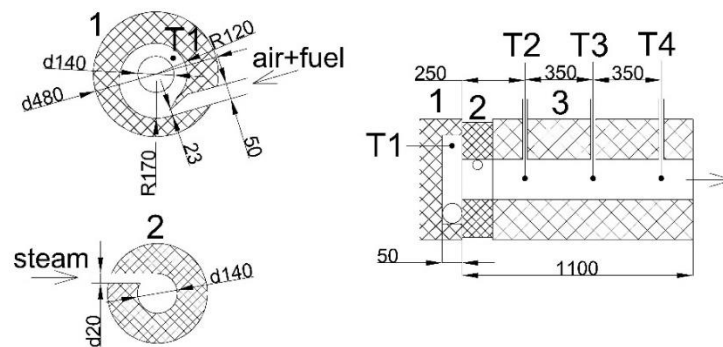
Coal is preliminarily milled in a hammer mill, and then mechanically activated on a disintegrator. Granulometric compositions (Fig. 1) were calculated according to the Rosin – Rammler equation using sieve analysis on sieves of 1000, 200, 100, 63, 40  $\mu\text{m}$ .



**Figure 1.** Granulometric composition of coal.

### 2.2. Experimental method

Experimental studies were carried out using the IT SB RAS entrained-flow gasifier with a fuel capacity of 1 MW. For these studies, the gasifier was modified. To increase the residence time and improve mixing of the flows inside the gasifier, the method of supplying steam to the reactor was changed. Instead of an axial feed through a nozzle located at the end of the swirler, steam was supplied tangentially through an insert located after the swirler (Fig. 2). Temperature was measured by T1-T4 chromel-alumel thermocouples using an automated data acquisition system. The gas composition ( $\text{O}_2$ ,  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{H}_2$ ,  $\text{NO}$ ,  $\text{SO}_2$ ) was measured by the Test-1 gas analyzer. Gas sampling was done through thermocouple fittings. The multistage air supply to the reaction chamber was realized by suction cups through leaks in the fittings for installing thermocouples and was regulated by changing the vacuum created by the smoke exhauster.



**Figure 2.** Scheme of gasifier. 1 — swirler, 2 — insert for tangential steam supply, 3 — reaction chamber.

The gasifier coal is ignited by a propane burner. After 2-3 minutes the temperature in the swirler reaches 800-1000°C. Then, within 30 minutes, the walls of the reactor are heated in the mode of incomplete combustion of coal with a stoichiometric coefficient of 0.8. Next, air-steam conversion modes are investigated. The experimental program is shown in table 2.

**Table 2.** Program of experiments.

№	Coal flow rate, kg/h	Air flow rate, m <sup>3</sup> /h	Steam flow rate, kg/h	Steam/coal, kg/kg	Stoichiometric coefficient
1	13,0	43,7	0,0	0,0	0,51
2	12,0	40,4	2,7	0,2	0,51
3	11,2	37,6	4,7	0,4	0,51
4	10,5	35,2	6,3	0,6	0,51
5	9,8	33,0	7,9	0,8	0,51

### 2.3. Numerical method

A numerical study of the experiments is performed using the CFD model of solid fuel entrained-flow gasification. The model is described in detail in [5-7].

## 3. Results and discussion

### 3.1. Experiment results

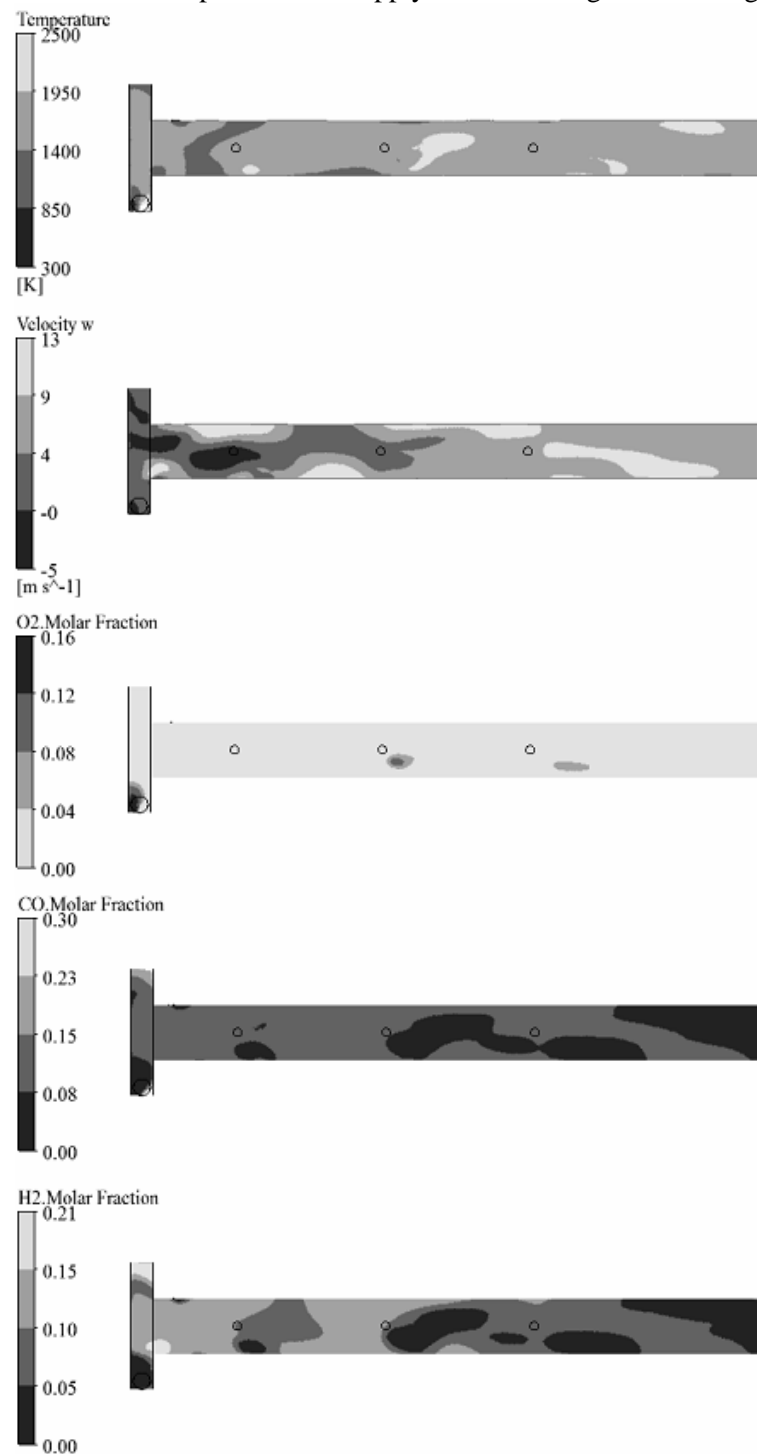
The resulting average temperature at the measurement points along the gasifier and the composition of the dry synthesis gas at the outlet of the gasifier are shown in table 3.

**Table 3.** Experiment results.

№	Temperature, °C				Volume fraction, % vol.				Q, MJ/m <sup>3</sup>
	T1	T2	T3	T4	CO	CO <sub>2</sub>	H <sub>2</sub>	O <sub>2</sub>	
1	1260	1270	1180	1120	2,7	14,5	3,3	4,5	0.70 1.92 2.17 1.95
2	1308	1273	1188	1117	7,7	13,1	8,8	1,8	
3	1300	1260	1187	1123	6,9	15,2	12,0	1,0	
4	1300	1261	1213	1155	6,2	15,6	10,8	1,0	
5	1300	1230	1182	1156	6,0	15,1	9,7	1,0	

### 3.2. Results of numerical calculations

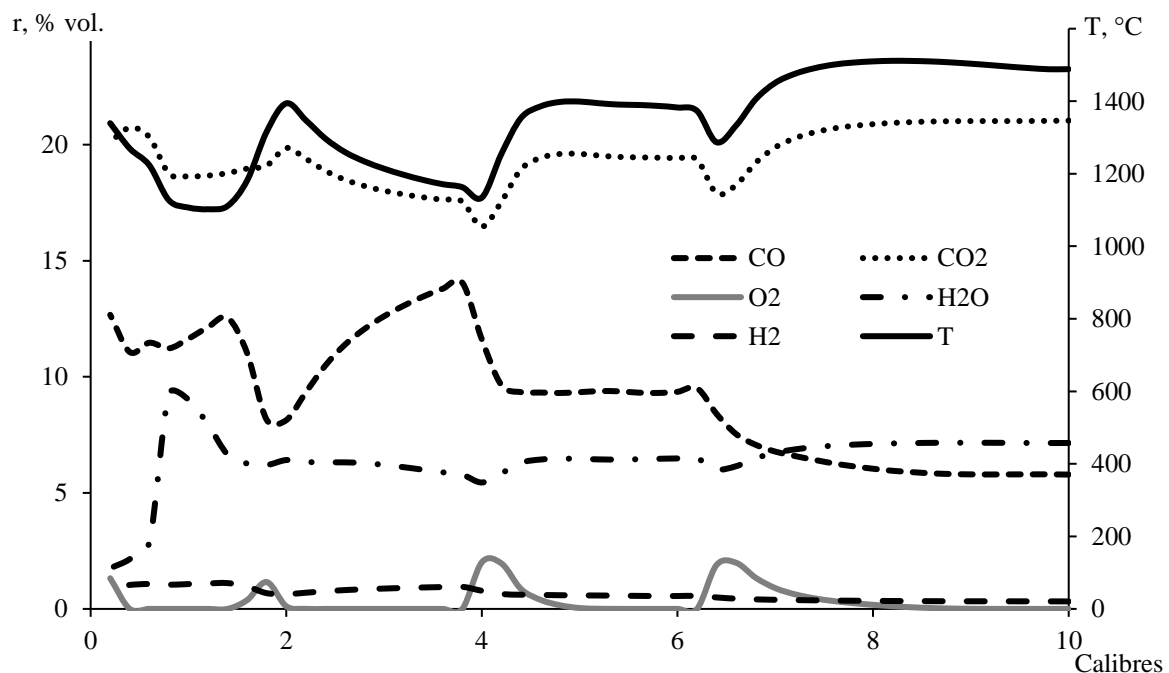
The analysis of the case with three points of air supply to the reacting chamber is given below (Fig. 3).





**Figure 3.** Distribution of variables in the longitudinal section of the gasifier.

The temperature distribution in the longitudinal section of the gasifier indicates the presence of flares in the places of air supply (maximum temperatures). In this case, the minimum temperature is located in the swirler, since a large amount of cold reagents is fed into it. The analysis of axial velocity allows one to determine the presence and location of regions with reverse flows. In the region after the first air supply point, the reverse flows almost completely disappear. Oxygen zones are localized near the points of air supply, and oxygen at the first point burns much faster than others due to the high concentration of combustible syngas components. The CO concentration is maximum in the swirler due to the reducing atmosphere and decreases after each air supply point. The hydrogen content has two maxima: in the swirler and at the point of steam supply due to the hydrogasification reaction. A steam jet makes 1-2 turns until it collapses in the gas stream. The cross section average values of the variables along the gasifier are shown in Figure 4.



**Figure 4.** The cross-sectional average variables values along the gasifier.

When all three air supply points are taken into account, the calculated data coincide with the experimental data, which indicates the successful validation of the CFD model used. According to the results of CFD modeling, the nature of the process that occurs in each section of the gasifier is clearly traced. In the swirler, an intense reaction of coal and oxygen occurs, which leads to an increase in CO<sub>2</sub> and H<sub>2</sub>O. At the point of steam supply, an increase in the concentration of hydrogen is observed. A

zone of sharp drop in CO and H<sub>2</sub>, as well as an increase in CO<sub>2</sub> and H<sub>2</sub>O, are formed near the air supply points.

### Conclusions

The conducted experimental and calculated studies of air-steam-blown gasification allow determining the effect of steam supply and multistage air supply on the features of the gasification process. Steam injection lowers the temperature of the gas mixture, increases the concentration of hydrogen due to the hydrogasification reaction. The air supply to the reaction chamber increases the temperature of the mixture due to the burning of part of the syngas, while the syngas heating value is reduced by an appropriate amount. The maximum concentration of the syngas combustible components (and hence syngas heating value) is observed before the second point of air supply to the reaction chamber.

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### References

- [1] Ryzhkov A, Bogatova T, Gordeev S 2018 *Fuel* **214** 63–72
- [2] Smoot L D, Hill S C, Xu H 1998 *Progress in Energy and Combustion Science* **24-5** 385–408
- [3] Ryzhkov A F, Bogatova T F, Lingyan Z and Osipov P V 2016 *Thermal Engineering* **63** 791–801
- [4] Hashimoto T, Sakamoto K and Kitagawa Y 2009 *Mitsubishi Heavy Industries Technical Review* **46-2** 1–5
- [5] Abaimov N A and Ryzhkov A F 2015 *Thermal Engineering* **62** 767–72
- [6] Chernetskiy M Y, Kuznetsov V A, Dekterev A A, Abaimov N A and Ryzhkov A F 2016 *Thermophysics and aeromechanics* **23** 615–26
- [7] Abaimov N A, Butakov E B, Burdukov A P, Osipov P V, Ryzhkov A F 2020 *Fuel* **271** 117487